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Visbreaking: A technology of the past and the future

J.G. Speight *

CD&W Inc., 2476 Overland Road, Laramie, WY 82070, USA

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Abstract Because of their relative simplicity of design and straightforward thermal approach, visbreaking processes will not be ignored or absent from the refinery of the future. However, new and improved approaches are important for the production of petroleum products. These will include advances in current methods, minimization of process energy losses, and improved conversion efficiency. In addition, the use of additives to encourage the preliminary deposition of coke-forming constituents is also an option. Depending upon the additive, disposal of the process sediment can be achieved by a choice of methods.

1. Introduction

Balancing product yield and market demand, without the manufacture of large quantities of fractions having low commercial value, has long required processes for the conversion of hydrocarbons of one molecular weight range and/or structure into some other molecular weight ranges and/or structures. The basic process is the *cracking processes* in which high boiling constituents of petroleum are cracked (thermally decomposed) into lower molecular weights and lower boiling molecules, although reforming, alkylation, polymerization, and hydrogen-refining processes have wide applications in producing premium-quality products [1–4].

Visbreaking is one of several cracking methods used in the petroleum industry to process crude oil and other petroleum products for commercial use [1–4]. In fact, the visbreaking process occurs predominantly in the liquid phase, and many other liquid-phase cracking processes, while not actually called visbreaking, actually operate in a visbreaking mode. These processes give the impression that visbreaking operations are no longer used in refineries. This is far from the truth; the visbreaking process is still a valuable process. The major process variables are (1) feedstock type, (2) temperature, (3) pressure, and residence time, which need to be considered to control the extent of cracking.

2. The visbreaking process

Visbreaking (*viscosity reduction, viscosity breaking*), a mild form of thermal cracking, insofar as thermal reactions are not allowed to proceed to completion and are interrupted by quenching, was developed in the late 1930s to produce more desirable and valuable products (visbreaking is a relatively *mild* thermal cracking operation). The process is used to reduce the viscosity of residua to produce fuel oil that meets specifications [1–7].

Published literature pertaining to the visbreaking process has been extensively analyzed and includes investigations of the following parameters:

(1) The effect of feedstock properties on the process;
(2) The effect of feedstock properties on fuel oil stability;
(3) Chemical pathways and mechanisms;
(4) Reaction kinetics;
(5) Coking and fouling;
(6) Sensitivity of the operating variables, such as temperature, pressure, and residence time;
(7) Visbreaker design;
(8) Liquid-phase mixing;
(9) Mathematical modeling of the visbreaker, which includes the behavior of the coil visbreaker and the soaker visbreaker [4,7].

Visbreaking conditions range from 455 to 510 °C (850 to 950 F) at a short residence time, and from 50 to 300 psi at the heating coil outlet. It is the short residence time that brings to visbreaking the concept of being a mild thermal reaction in contrast to, for example, the delayed coking process, where

* Tel.: +1 307 745 6069, +1 307 760 7673 (Mob.); fax: +1 307 721 3128.
E-mail address: JamesSp8@aol.com.

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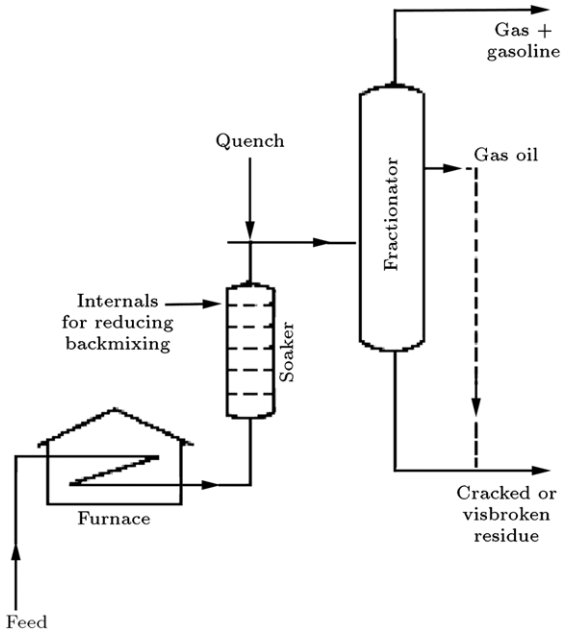

Figure 1: A soaker visbreaker.
Source: OSHA Technical Manual, Section IV, Chapter 2: Petroleum Refining Processes. http://www.osha.gov/dts/osta/otm/otm_iv/otm_iv_2.html.

residence times are much longer and thermal reactions are allowed to proceed to completion. Liquid-phase cracking takes place under these low-severity conditions to produce some naphtha, as well as material in the kerosene and gas oil boiling range. The gas oil may be used as additional feed for catalytic cracking units, or as heating oil.

In the process, the feedstock (usually residuum or tar sand bitumen) is passed through a furnace where it is heated to a temperature of 480 °C (895 F) under an outlet pressure of about 100 psi (Figure 1). The cracked products are then passed into a flash-distillation chamber. The overhead material from this chamber is then fractionated to produce naphtha and light gas oil. The liquid products from the flash chamber are cooled with a gas oil flux and then sent to a vacuum fractionator. This yields a heavy gas oil distillate and a residuum of reduced viscosity [4,8]. A 5%–10% conversion of residuum to naphtha is usually sufficient to afford at least an approximate five-fold reduction in viscosity. Reduction in viscosity is also accompanied by a reduction in the pour point. An alternative option is to use lower furnace temperatures and longer times, achieved by installing a soaking drum between the furnace and the fractionator. The disadvantage of this approach is the need to remove coke from the soaking drum.

Mild cracking conditions (low feedstock conversion per cycle) favor a high yield of naphtha with low gas production and decreased coke production. With limited conversion per cycle, the higher boiling residues must be recycled. However, the recycled oils become increasingly refractory with each pass through the thermal zone, and, if such oils are not required as a fuel oil stock, they may be subjected to a coking operation to increase gasoline yield or refined by means of a hydrogen process.

The process is a relatively low-cost and low severity approach to improving the viscosity characteristics of the residue, without attempting significant conversion to distillates. Low residence times are required to avoid coke formation, although additives can help to suppress coke deposits on the tubes of the furnace. By reducing the viscosity of the non-volatile fraction, visbreaking reduces the amount of the more valuable distillate heating oil that is required for blending to meet the fuel oil specifications. The process is also used to reduce the pour point of a waxy residue.

Two visbreaking processes are commercially available: the *soaker visbreaker* and the *coil visbreaker*.

The *soaker visbreaking process* (a low-temperature- high-residence-time process) (Figure 1) [1–4] achieves a minor degree of conversion within the heater, but the majority of the conversion occurs in a reaction vessel (soaker) that holds the two-phase effluent at an elevated temperature for a predetermined length of time to allow cracking to occur before being quenched. The oil then passes to a fractionator. A soaker visbreaker uses lower temperatures than in coil visbreaking. The comparatively long duration of the cracking reaction is used instead to achieve the desired results.

Product quality and yields from the coil and soaker drum design are essentially the same at a specified severity, being independent of visbreaker configuration. By providing the residence time required for achieving the desired reaction, the soaker drum design allows the heater to operate at a lower outlet temperature (thereby, saving fuel), but there are disadvantages.

The main disadvantage of the soaker visbreaking process is the decoking operation of the heater and soaker drum, and although the decoking requirements of the soaker drum design are not as frequent as those of the coil-type visbreaker, the soaker design requires more equipment for coke removal and handling. The customary practice of removing coke from a drum is to cut it out with high-pressure water, thereby, producing a significant amount of coke-laden water that needs to be handled, filtered, and then recycled for use again.

The *coil visbreaking process* (high-temperature-short-residence-time process) [1–4] differs from soaker visbreaking insofar as the coil process achieves conversion by high-temperature cracking within a dedicated soaking coil in the furnace. Products exiting the furnace are quenched to halt the cracking reactions. This is frequently achieved by heat exchange with the virgin material being fed to the furnace, or a stream of cold oil (usually gas oil) is used to the same effect, and the gas oil is recovered and re-used. The extent of the cracking reaction is controlled by regulation of the speed of flow of the feedstock through the furnace tubes. The quenched oil then passes to a fractionator, where the products of the cracking (gas, LPG, gasoline, gas oil and tar) are separated and recovered.

The main advantage of the coil-type design is the two-zone fired heater that provides better control of the material being heated and, with the coil-type design, decoking of the heater tubes is accomplished more easily by the use of steam-air decoking.

The higher heater outlet temperature specified for a coil visbreaker is an important advantage of coil visbreaking. The higher heater outlet temperature is used to recover significantly higher quantities of heavy visbroken gas oil. This capability cannot be achieved with a soaker visbreaker without the addition of a vacuum flasher.

In terms of product yield, there is little difference between the two options (soaker visbreaker compared to coil visbreaker approaches). However, each offers significant advantages in particular situations. For example, the cracking reaction forms coke as a byproduct. In coil visbreaking, this lies down in the tubes of the furnace and will eventually lead to the fouling or blocking of the tubes.

Briefly, fouling (a deposit buildup in refinery processes that impedes heat transfer and/or reduces throughput) is the leading

cause of diminished efficiency and productivity in refineries. The energy lost due to this inefficiency must be supplied by burning additional fuel or reducing feed. While most fouling is caused by the deposition of heavier hydrocarbon species coming directly from the crude oil, a small undetermined percentage is related to corrosion and scale deposits, either actively participating as loose corrosion products or by scale acting as a substrate for hydrocarbon deposition.

Fouling will also occur in the drum of a soaker visbreaker, though the lower temperatures used in the soaker drum lead to fouling at a much slower rate. The coil visbreaker, therefore, requires frequent de-coking. Soaker drums require far less frequent attention, but, when taken out of service, this normally requires a complete halt to the operation.

The lower temperatures used in the soaker approach mean that these units use less fuel. In cases where a refinery buys fuel to support process operations, any saving in fuel consumption could be extremely valuable. In such cases, soaker visbreaking may be advantageous.

The shell soaker visbreaking process is suitable for the production of fuel oil by residuum (atmospheric residuum, vacuum residuum, or solvent deasphalter bottoms) viscosity reduction, with the maximum production of distillates. The basic configuration of the process includes the heater, soaker and fractionators, and more recently, a vacuum flasher to recover more distillate products [1–4]. The cut point of the heavy gas oil stream taken from the vacuum flasher is approximately 520 °C (970 F).

In the process, the feedstock is preheated before entering the visbreaker heater, where the residue is heated to the required cracking temperature. Heater effluent is sent to the soaker drum, where most of the thermal cracking and viscosity reduction takes place under controlled conditions. Soaker drum effluent is flashed and then quenched in the fractionators, and the flashed vapors are fractionated into gas, naphtha, gas oil, and visbreaker residue. The visbreaker residue is steam-stripped at the bottom of the fractionator and pumped through the cooling circuit for further processing. Visbreaker gas oil, which is recovered as a side stream, is steam-stripped, cooled and sent for further processing.

As expected, product yields are dependent on feed type and product specifications [1–4]. The heavy gas oil stream from the visbreaker can be used as feedstock for a thermal distillate cracking unit or for a catalytic cracker for the production of lower boiling distillate products.

However, a recurring issue with the soaker visbreaker is the need to periodically de-coke the soaker drum and the inability of the soaker process to easily adjust to changes in feedstock quality, because of the need to fine tune two process variables, temperature and residence time. Recent combinations of visbreaking technology and the addition of new coil visbreaker design features have provided the coil process with a competitive advantage over the traditional soaker visbreaker process. Limitations in heater run length are no longer a problem for the coil visbreaker. Advances in visbreaker coil heater design now allow for the isolation of one or more passes through the heater for decoking, eliminating the need to shut the entire visbreaker down for furnace decoking.

Overall, the main limitation of the visbreaking process, and for that matter, all thermal processes, is that products can be unstable, due to the presence of unsaturated products. For example, thermal cracking at low pressure produces olefins (and di-olefins) particularly in the naphtha fraction. These olefins give a very unstable product, which tends to undergo secondary reactions to form gum and intractable non-volatile tar.

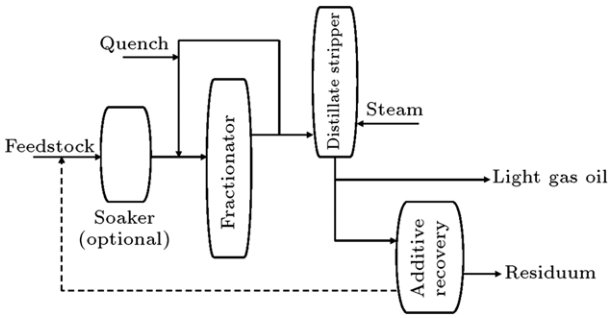

Figure 2: The Aquaconversion process.

The reduction in viscosity of distillation residua tends to reach a limiting value with conversion, although the total product viscosity can continue to decrease. The minimum viscosity of the unconverted residue can lie outside the range of allowable conversion, if sediment begins to form. When shipment of the visbreaker product by pipeline is the process objective, addition of diluents, such as gas condensate, can be used to achieve a further reduction in viscosity.

In spite of the various limitations outlined above, visbreaking has much potential and, in fact, remains an important, relatively inexpensive, bottom-of-the-barrel upgrading process in many areas of the world.

3. Options for heavy feedstocks

Refinery evolution (to accommodate the more complex difficult-to-convert heavy oil, residua, and tar bitumen) has seen the introduction of a variety of heavy feedstock cracking processes [1–4]. Some use catalysts (and are of necessity included here) that center on the concept of visbreaking. These processes are different from one another in the cracking method, cracked product patterns and product properties, and are employed in refineries according to their respective features.

3.1. Aquaconversion process

The *Aquaconversion Process* (Figure 2) is a hydrovisbreaking technology that uses catalyst-activated transfer of hydrogen from water added to the feedstock. Reactions that lead to coke formation are suppressed and there is no separation of asphaltene-type material [1,3,4,9]. An important aspect of Aquaconversion technology is that it does not produce any solid by-product, such as coke, nor does it require any hydrogen source or high-pressure equipment. In addition, the Aquaconversion process can be implanted in the production area, and thus, the need for an external diluent and its transport over large distances is eliminated.

3.2. High conversion Soaker Cracking (HSC) process

The HSC process is a cracking process designed for moderate conversion; higher conversion than visbreaking but lower conversion than coking [1–4,10]. The process can be used to convert a wide range of feedstocks with high sulfur and metals content including heavy oils, oil sand bitumen, residua, and visbroken residua.

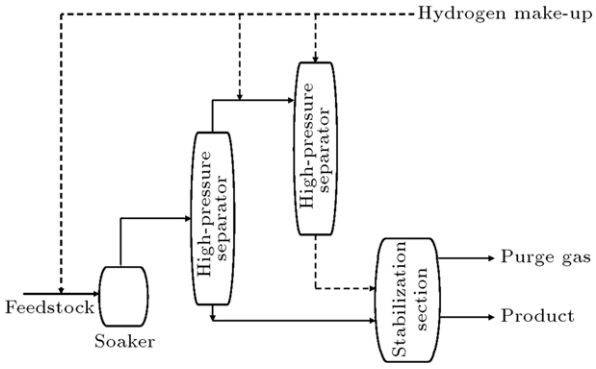

Figure 3: The Tervahl-*T* process.

In the process, the preheated feedstock enters the bottom of the fractionator, where it is mixed with the recycle oil. The mixture is pumped up to the charge heater and fed to the soaking drum (ca. atmospheric pressure, steam injection at the top and bottom), where sufficient residence time is provided to complete the thermal cracking. In the soaking drum, the feedstock and some products flow downward, passing through a number of perforated plates, while steam with cracked gas and distillate vapors flow through the perforated plates counter-currently.

The volatile products from the soaking drum enter the fractionators, where the distillates are fractionated into the desired product oil streams including a heavy gas oil fraction. The cracked gas product is compressed and used as refinery fuel gas after sweetening. The cracked oil product, after hydrotreating, is used as fluid catalytic cracking or hydrocracker feedstock. The residuum is suitable for use as boiler fuel, road asphalt, binder for the coking industry, and as a feedstock for partial oxidation.

3.3. Tervahl-T process

The Tervahl-*T* process (Figure 3) offers options that allow the process to accommodate differences in the feedstock, as well as the desired sale of products.

In the process [1–4,11], the feedstock is heated to the desired temperature using the coil heater and heat recovered in the stabilization section, and held for a specified residence time in the soaking drum. The soaking drum effluent is quenched and sent to a conventional stabilizer or fractionators, where the products are separated into the desired streams [1–4]. The gas produced from the process is used for fuel.

In the related Tervahl-*H* process (a hydrogenation process, but covered here for convenient comparison with the Tervahl-*T* process), the feedstock and hydrogen-rich stream are heated using heat recovery techniques and a fired heater, and held in the soak drum as in the Tervahl-*T* process. The gas and oil from the soaking drum effluent are mixed with recycled hydrogen and separated in the hot separator, where the gas is cooled and passed through a separator and recycled to the heater and soaking drum effluent. The liquids from the hot and cold separator are sent to the stabilizer section, where purge gas and synthetic crude are separated. The gas is used as fuel and the synthetic crude can now be transported or stored.

4. Process innovations

Petroleum refining is growing increasingly complex, due to lower-quality crude oil [2–4,8,12], crude oil price volatility, and environmental regulations, which require cleaner manufacturing processes and higher-performance products. In many cases, technology research and development have led to increasingly complex processing sequences and process units as the key to meeting these challenges and maintaining the health and profitability of the industry. While process innovations have been introduced in the form of varying process options, several use piggy-back techniques, where one process works in close conjunction with another [8]. There are other options that have not yet been introduced or even invented, but may well fit into the refinery of the future [13–18].

In addition, the use of additives to encourage preliminary deposition of coke-forming constituents is also an option. This is similar, in principle, to the use of small amounts of coal in the former Canmet hydrocracking process [4,8] (now the UOP Uniflex process) or in the Cherry-*P* process, where coal acts as a scavenger to prevent the buildup of coke on the reactor wall [1–4]. In this case, the visbreaker might be operated at a point beyond the usual operating parameters, so that coke or sediment deposition is encouraged, leaving the liquid product relatively coke-former free. Depending upon the additive, disposal of the process sediment can be achieved by a choice of methods.

Because of the relative simplicity of design and straightforward thermal approach, visbreaking processes will not be ignored or absent from the refinery of the future [8]. These processes should not be ignored, because they have the ability to adapt, by virtue of their relative simplicity, to the changing markets of heavy feedstock processing, and tar sand bitumen processing. However, new and improved approaches are important for the production of petroleum products. These will include advances in current methods, the minimization of process energy losses, and improved conversion efficiency — in particular (1) mitigation of fouling in heat exchangers, and (2) improved conversion efficiency.

Visbreaking may be the most under-estimated and/or under-valued process in a refinery, although the process is not seen as making a major comeback in US refineries [19], this opinion may require some re-evaluation [8].

The severity of visbreaker operation is generally limited by the stability requirement of the blended fuel oil and the extent of fouling and coke lay-down in the visbreaker heater. The former requirement means that the stability of the residue must be sufficient to ensure that the finished fuel resulting from blending with diluents (that are less aromatic than the residue) is stable, and that asphaltene flocculation does not occur. Where the residue is converted to an emulsion, blend stability is improved and severity/conversion can be increased, subject to acceptable levels of heater fouling and coke deposition [20]. Operational modifications, such as increasing steam injection or re-cycling heavy distillates from the visbreaker fractionator, may help mitigate the coking tendency and enhance yield, while some relatively low-cost options to increase heater capacity might be implemented in certain instances.

Foster Wheeler/UOP now offer commercial, proprietary technology, which allow coil visbreaker operators to recover incremental heavy gas oil with an end point of approximately 450 °C (840 F) for FCC/hydrocracker feed, without having to resort to vacuum flashing. Higher conversion versions of visbreaking are available from companies including Shell Global Solutions and Foster Wheeler/UOP (Aquaconversion process), while still achieving a stable fuel oil product.

The need for more and heavier feedstock processing units has been a trend since the start of the industry. Year by year, the density and sulfur content of available crudes has been slowly rising [2–4,12].

5. Conclusions

The current global petroleum market will continue to offer opportunities for bottom-of-the-barrel technology to play an important role in the refiner's continuous efforts to balance available crude quality with market demands. However pessimistic a future market and refining outlook may be, they still seem to include ample amounts of heavier and more sour crudes in addition to avid demands for transportation fuels.

There is a need to improve resid conversion processes, such as visbreaking technologies. Part of the future growth will be at, or near, heavy crude and bitumen production sites in order to decrease heavy crude viscosity and improve the quality of easy transportation and open markets for crudes of otherwise marginal value. Visbreaking will then be considered a conversion process, rather than a process by which to produce fuel oil that meets specifications.

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James G. Speight has more than forty years of experience in areas associated with (1) the properties and recovery of reservoir fluids including heavy oil, and tar sand bitumen, (2) refining conventional petroleum, as well as heavy oil, tar sand bitumen, synthetic fuels, and biofuels, (3) the properties of fuels, synthetic fuels, and biofuels, (4) the properties, behavior, and processing of natural gas, including gas-to-liquids, (5) the properties and behavior of coal, including coal liquids, and (6) the properties and behavior of oil shale, including shale oil. He is author of more than four hundred publications, reports and presentations, and has taught more than seventy courses. Dr. Speight is also Editor and Founding Editor of "Petroleum Science and Technology", and Editor of "Energy Sources. Part A: Recovery, Utilization, and Environmental Effects", and "Energy Sources. Part B: Economics, Planning, and Policy".